Meditation, Stress Processes, and Telomere Biology

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Abstract

Both theoretical and empirical work support the notion that meditation training can improve telomere regulation, which may ultimately contribute to healthy aging. Yet, the psychological and biological mechanisms underlying these changes remain underspecified, as do the contexts and boundary conditions in which these changes occur. Here we summarize studies investigating the effects of various meditation-based interventions on telomere biology, making suggestions for future research. We then propose a model describing how meditation training...
may impact acute and habitual stress responses as pathways to improved cell aging.

Telomeres are DNA-protein complexes that cap and protect eukaryotic chromosomes. These dynamic structures are regulated by an intricate system of proteins and other molecular components, including telomerase—an enzyme capable of elongating telomeres. When telomeres become too short, critical cellular events occur, including cell death or states of prolonged senescence and inflammatory output. As such, **telomere length (TL)** serves as a reliable indicator of many age-related diseases (e.g., dementia and heart disease [1]). Studies of genetics show that telomere biology plays a small but causal role in disease processes: for example, genetic loading for short TL predicts degenerative diseases such as cardiovascular disease, whereas genetic variation for longer telomeres predicts propensity for certain cancers, including glioma [2].

Telomeres generally shorten slowly across the lifespan. There is, however, some degree of malleability to this as telomeres tend to shorten more quickly in individuals exposed to long-term psychosocial adversity [3], but appear to stabilize or possibly lengthen in individuals engaged in positive lifestyle interventions (e.g., [4]). Meditation training is one such intervention that seems to beneficially affect telomere biology. In a previous theoretical model, we explored the impact of mindfulness meditation on TL [5]. In the decade since this model was published, a small body of research has emerged addressing the relationship between meditation practice and telomere-related outcomes (telomere length, telomerase activity, or telomere-related gene expression). Here, we review this empirical work and offer an updated model, depicted in **Figure 1**, which illustrates how various aspects of meditation training may impact telomeric regulation by influencing acute and habitual stress processes.
What we know so far:

A total of 19 studies have examined telomere biology in relation to meditation [6–24]. These studies vary in quality, though many constitute promising pilot studies that warrant replication and extension. Two cross-sectional studies found longer telomeres in experienced meditators compared to meditation-naive controls (n=20 [7*]; n=13 [6], in women only). The remaining 17 studies examined telomere-related outcomes in relation to interventions involving or emphasizing meditation practice (Table 1). Of the eleven studies measuring telomerase activity (TA), nine found intervention-related increases [9,10,18–24] or higher TA in the treatment group following intervention [17], while two found no significant changes in TA [8*,24]. By contrast, just two of the nine studies measuring TL—which involved interventions of relatively high intensity or duration—showed increased TL in the treatment group [8*,23]. The remaining seven studies found no significant change in TL [9–15].

Only four studies have assessed TA and TL concurrently, each of which reported significant intervention-related changes in one measure but not the other [8*–10,24]. These findings suggest that TA and TL have different kinetics and fluctuate on different time scales, consistent with the observation that TA and TL are generally uncorrelated in cross-sectional studies [25]. We hypothesize that meditation training promotes phasic increases in TA, which eventually lead to longer telomeres, though the duration of training needed to elicit these effects is unknown. Initial evidence suggests that these changes can happen rapidly: intensive retreat studies of experienced meditators have shown modest increases in TA in as little as one week [22*] and increases in TL in as little as three weeks [8*]. Because TA and TL were only assessed at the end of these interventions, the longevity of these effects is unknown.

It is largely assumed that meditation training influences telomere biology by reducing
psychological stress, though only a few studies have assessed whether stress-related processes actually mediate these relationships. Intervention-related increases in TA have been linked to improvements in quality of life [19], fewer intrusive thoughts [23], and reductions in anxiety, chronic stress, and basal cortisol [18]—though these associations have not been observed in all cases [9,14]. Another study found that increases in perceived control and purpose in life, and decreases in neuroticism, were associated with higher levels of TA following an intensive retreat [17]. More direct tests of stress-related psychological and biological meditators are needed to better understand these relationships over time.

Although the available evidence suggests that meditation training can improve telomere maintenance, it is unclear how and under what conditions these effects are achieved, and how long they persist. Because telomere regulation is dynamic and involves complex temporal features that are not yet fully understood, future studies should include more frequent measurements using gold standard methods [26**,27**]. As telomere biology varies by cell type, it will be informative for studies to assess TL in tissues with stable cell type distributions (e.g., buccal cells), in addition to more commonly used blood samples, which include a mix of shifting immune cell types (see Lin et al. [27**] for a discussion of the pros and cons of measuring TL in different sample types and with various assay methods). Finally, to gain the clearest mechanistic understanding, studies should measure psychological and physiological stress processes alongside multiple indicators of telomere biology and other biomarkers of aging.

**Stress processes and their relation to telomere biology**

The acute stress response traditionally refers to a range of cognitive, affective, behavioral, and physiological reactions to discrete stressors [28*], which are shaped by cognitive biases and basal physiological states. This multi-system response can involve **anticipatory**
arousal before a stressful event, peak reactivity during the event, and recovery to baseline following the event. Maladaptive forms of this acute stress response may lead to alterations in telomere regulation. For example, exaggerated autonomic reactivity has been associated with lower immune cell TA [29], and higher cortisol reactivity to stressors has been associated with shorter immune cell telomeres [30*] (but not buccal cell TL [31]). Perseverative cognitions, such as worry and rumination, can exacerbate profiles of heightened physiological reactivity and delayed recovery [32] and may serve as internal stressors in and of themselves. Importantly, shorter telomeres have also been linked to perseverative cognitions, including negative mind wandering [33] and greater anticipatory threat appraisals to an acute stressor [34].

Acute stress reactivity profiles are influenced by allostatic states, including basal levels of autonomic and neuroendocrine activity, metabolic hormones, and inflammation. Chronic exposure and prolonged reactivity to stressors can contribute to dysregulated allostatic states, with deleterious health consequences (e.g. [35]). Telomere regulation appears to be implicated in this relationship, as shorter telomeres and lower telomerase levels have been associated with lower vagal tone, and higher basal levels of cortisol, inflammation, and oxidative stress [3].

The acute stress response is activated by perceptions of threat to the physical or social self [36], yet these perceptions vary between people and between physical, social, and cultural contexts. Cognitive biases are the habitual mental filters that influence one’s interpretations of the world, including mental representations of the self and others, and perceptions of one’s environment. These cognitive biases are shaped by life experience. For example, having a history of early life adversity can lead one to anticipate negative events and to interpret neutral stimuli as negative (e.g. [37]). Cognitive biases that prime individuals to be hypervigilant to their environment—due to real or perceived threats—can lead to heightened allostatic states. It may be
that regularly feeling unsafe indirectly signals to cellular mediators that it is more important to sustain heightened biological stress arousal (i.e., to be on alert for threats) than to put energy towards cellular restoration. Along these lines, personality traits such as pessimism, neuroticism, and hostility have been linked to prolonged stress reactivity and shorter telomeres [38], suggesting that one’s habitual interpretations of the world contribute to the relationship between stress exposure and telomere regulation.

Initial evidence suggests that various forms of meditation training can beneficially affect allostatic states (e.g., immune system functioning [39]) and the anticipatory [40], reactivity (e.g., [41]), and recovery [42] phases of the acute stress response. Yet these findings are inconsistent (for a review of cortisol studies, see [43]). Meditation interventions can vary significantly in the practices they emphasize, their pedagogical frameworks, and in their training environments—all of which may influence stress processes. Similarly, some practices may be more appropriate for particular individuals depending on the types of maladaptive stress responses they are most prone to (e.g., greater anticipatory threat or prolonged recovery). Accounting for these variables will facilitate more direct and nuanced hypothesis testing regarding the effects of meditation training on stress processes and outcomes.

**Effects of meditation training on stress processes**

Meditation practices represent a class of mental training techniques intended to regulate a range of psychological processes—particularly those having to do with perceptions of reality and the self [44*,45]. As such, we expect these techniques to target the cognitive biases that shape acute stress appraisals and responses, as well as the perseverative cognitions that prolong stress reactivity. In this way, continued meditation training should support experiential learning and self-understanding that lead to lasting improvements in health.
Meditation techniques can be usefully categorized according to the cognitive mechanisms they are believed to target. One contemporary classification system posits three families of practice: attentional, deconstructive, and constructive [44**]. The attentional family comprises practices used to train the self-regulation of attention. One common practice involves continually directing attention to the unfolding of one’s present-moment interoceptive or sensory experience (e.g., sensations of the breath), monitoring this attention, and bringing it back when it inevitably strays. Attention practices are thought to strengthen meta-awareness, the ability to observe and monitor one’s internal processes of thinking and feeling [44**,45]. As a result, awareness is brought to bear on aspects of emotional experience that may otherwise go unnoticed, including bodily sensations, thoughts, and environmental stimuli, which may lead to improvements in emotion identification and regulation [46]. Training attention to one’s present-moment experience has also been shown to reduce elaborative processing of stimuli [47] and to inhibit habitual behavioral responding (e.g., [48]). These changes may lead to more efficient and flexible uses of attentional resources, promoting more accurate and less catastrophic appraisals of one’s present experience, as well as more adaptive behavioral responses to stressful events.

The deconstructive family refers to a set of self-inquiry techniques used to foster insight into processes of perception, emotion, and cognition. A common goal of such practices is to deconstruct maladaptive models of the self, others, and the world by interrogating the causes and conditions of one’s present experience, and by observing the impermanence of phenomena (see [44**] for an illustration of this using the experience of anger as an example). One cognitive faculty targeted by deconstructive practices is dereification (also known as decentering or cognitive defusion), which occurs when thoughts, feelings, and perceptions are observed as temporary mental phenomena rather than accurate reflections of reality [44**–46]. Together,
dereification and meta-awareness may disrupt perseverative cognitions as well as the negative self-concepts and excessive self-referential processing implicated in depression and anxiety [44**,45,49,50]; they may also facilitate insights and reappraisals that support greater self-acceptance. Thoughts and events may also appear less threatening when understood as impermanent phenomena, and the ability to observe unpleasant experiences with greater granularity may similarly lessen their potency. These changes are likely to minimize experiential avoidance [46], which, in turn, may break the cycle of anticipatory anxiety, heightened reactivity, and prolonged recovery, in favor of more adaptive stress response profiles.

Finally, practices in the constructive family are intended to further cultivate psychological well-being by replacing maladaptive self-schemas with adaptive self-concepts [44**], and by developing prosocial qualities, such as kindness, compassion, empathetic joy and equanimity [51]. Psychological processes targeted by these practices include perspective taking, shifts in appraisal, and the generation of positive affect [44**,52], each of which may influence how acute stressors are perceived and responded to. These practices may be especially useful for managing acute stressors involving negative interactions with others. Indeed, initial evidence suggests that such practices alter acute responses to social-evaluative stressors. For instance, self-compassion training attenuated physiological and subjective stress reactivity to the Trier Social Stress Test (TSST) [53], and interventions involving dyadic meditation practices reduced cortisol reactivity to the TSST compared to attention-focused training [54].

Though each of these families of practice are likely to influence telomere regulation, the boundaries between them are not clear cut. Some practices are likely to target multiple psychological processes, and most meditation interventions combine several different practice types, making it difficult to distinguish their individual contributions. Additionally, individuals
will vary in how they interpret and implement these instructions [45], and the skills learned
during formal meditation practice may manifest in a myriad of ways in daily life.

**Meditation training contexts: safety and support**

Meditation training may uniquely affect stress responding by promoting perceptions of
safety—safety within the context of the self, in social exchanges, and by providing physically
safe environments. Traditional stress-health models assume that stress degrades health through
repeated activation of acute stress response systems (e.g, [55]). By contrast, the generalized
unsafety theory of stress assumes that stress-response systems are predisposed to respond to
threats, and are only inhibited by learned safety cues, including the presence of trusted
individuals [56*]. This reconfigured model shifts the emphasis from acute stressors that activate
stress responses, to the safety signals needed to dampen a threat-detection system that is ever at
the ready [56*]. From this perspective, fundamentally altering explicit and implicit appraisal
processes that modulate stress responding may require learning, or re-learning, safety cues until
they become believed and habitual.

Meditation training often occurs in the context of a highly supportive environment.
Residential retreats are the most extreme and unique example of this, where individuals are
sequestered from real-world threats and demands, in a safe natural environment with their basic
needs taken care of (see King et al., this issue [57]). This may be a particularly beneficial training
format for individuals prone to maladaptive acute stress responses or with more ingrained
telomere vulnerability factors, including experiences of early adversity, insecure attachments
[58], and neuroticism (the later indicated by our recent retreat study [8*]). Additionally,
relationships with trusted teachers and a community of similarly motivated practitioners may
promote feelings of safety and activate schemas of secure attachment and interconnectedness. These elements may play an important role in altering stress processes over and above the mental training aspects of meditation.

**Conclusion**

We have outlined several potential mechanisms through which meditation training may improve telomere biology via changes to habitual and acute stress processes (Figure 1). In articulating these pathways, this model may help to explain why a variety of meditation interventions, as well as other mind-body interventions, have been found to have positive effects on telomere biology as well as other stress-sensitive biological outcomes. As methods of measuring telomere biology become more reliable and available, the next generation of studies will be able to determine more definitively if meditation interventions impact telomere biology in a meaningful way. Understanding how these practices affect telomere biology will require a more systematic investigation of the various dimensions that make up meditation interventions, as well as better methods for capturing the phenomenological and psychological changes that might occur. Despite the complexity of these mind-body relationships, there is still a tremendous amount that can be learned about how meditation influences biological and cellular functioning.

**Conflicts of interest**

None of the four authors have any conflicts of interest to declare.
Acknowledgements

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References


7. *Alda M, Puebla-Guedea M, Rodero B, Demarzo M, Montero-Marin J, Roca M, Garcia-Campayo J: Zen meditation, length of telomeres, and the role of experiential avoidance and compassion. Mindfulness (NY) 2016, 7:651–659. This is the only study to have assessed telomere length in relation to meditation practice using high-throughput quantitative fluorescence in situ hybridization (HT-Q-FISH). There are several methods for measuring telomere length. PCR is often the most feasible to implement, but only provides average telomere length estimates for a given sample. HT-Q-FISH is more costly but measures telomere length in individual cells, providing more granular information.


22. *Epel ES, Puterman E, Lin J, Blackburn EH, Lum PY, Beckmann ND, Zhu J, Lee E, Gilbert A, Rissman RA, et al.: Meditation and vacation effects have an impact on disease-associated molecular phenotypes. Transl Psychiatry* 2016, 6:e880. This is the only meditation retreat study to account for the effects of the retreat environment and removal from daily life stressors by comparing experienced meditation practitioners, novice practitioners, and a vacation control group living in the same retreat environment.


26. **Thomas S: Telomeres as Sentinels for Environmental Exposures, Psychosocial Stress, and Disease Susceptibility. National Institute of Environmental Health Sciences and the National Institute on Aging Workshop Summary 2017.** At this workshop, leading experts in telomere biology discussed the challenges and opportunities of telomere research. This meeting summary offers an excellent overview for researchers new to the area.

27. **Lin J, Smith DL, Esteves K, Drury S: Telomere length measurement by qPCR - Summary of critical factors and recommendations for assay design. Psychoneuroendocrinology** 2018, In press. This review summarizes issues that arise when telomere length is measured using qPCR—addressing the selection of biological samples (e.g. blood, saliva etc.), the collection and storage of samples, and the DNA extraction and post-extraction phases of the assay procedure. The authors provide recommendations and guidance based on current literature.

disease development.


41. Rosenkranz MA, Lutz A, Perlman DM, Bachhuber DRW, Schuyler BS, MacCoon DG,


44. **Dahl CJ, Lutz A, Davidson RJ: Reconstructing and deconstructing the self: cognitive mechanisms in meditation practice. *Trends Cogn Sci* 2015, 19:515–523. These authors present a novel typology of meditation, classifying practices into three broad families based on the cognitive processes they are thought to target. This framework is useful for developing theories and making mechanistic predictions about specific practices.


53. Arch JJ, Brown KW, Dean DJ, Landy LN, Brown KD, Laudenslager ML: Self-


56. *Brosschot J, Verkuil B, Thayer J, Brosschot JF, Verkuil B, Thayer JF: Generalized Unsafety Theory of Stress: Unsafe Environments and Conditions, and the Default Stress Response. Int J Environ Res Public Health 2018, 15:464. This paper outlines a novel theory of psychological stress, which posits that individuals’ have an innate threat-detection system that is suppressed by learned safety cues. This model accounts for the occurrence of prolonged physiological stress responses that occur in the absence of any direct or acute stress stimuli (e.g., loneliness in humans), suggesting that these responses result from a lack of perceived safety.


Meditation training is expected to alter basal processes that influence acute stress responses, potentially resulting in fewer overall stress reactions. Training may also provide tools to reduce the severity of acute responses when they do occur. Only some of the mechanistic pathways proposed here have been tested. For example, there is evidence for the link between stress appraisals and telomere length [34] and for the ability of meditation training to enhance positive reappraisals (e.g., [59]), yet no intervention study has simultaneously assessed changes in stress appraisals and telomere biology to test this mediational pathway. With regard to perseverative cognitions, there is evidence that meditation training reduces rumination [60] and mind wandering [61], and that negative mind wandering is related to shorter telomeres [33], but no study has tested the association between telomere length and rumination. One small study of prostate cancer patients did, however, find that intervention-related increases in TA were associated with declines in individual’s intrusive thoughts about their diagnosis [23]. While this study found that changes in avoidance were not related to increases in TA, another study found that telomere length was inversely related to experiential avoidance [7*]. Intervention-related increases in TA have also been linked to declines in morning cortisol [18], though no meditation intervention study has assessed acute reactivity in relation to telomere outcomes. Finally, there are multiple biological mechanisms that may result in TL changes, including increases in intracellular TA, alternative lengthening of telomeres, latent virus reactivation, and shifts in cell distributions [62]. These
biological mechanisms will need to be considered to map out a more complete model.
Table 1: Meditation Interventions Measuring Telomere Outcomes

<table>
<thead>
<tr>
<th>Study</th>
<th>Participant</th>
<th>Random</th>
<th>Control intervention</th>
<th>Target intervention</th>
<th>Target intervention length and intensity</th>
<th>Sample collection</th>
<th>Cell type</th>
<th>Telomere-related assay method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jacobs et al. (2011)</td>
<td>Healthy exp, men &amp; w</td>
<td>Yes</td>
<td>W</td>
<td>Shamatha meditation retreat (n = 30)</td>
<td>12 weeks: silent residential retreat including meditation - 6 h/d + meditation retreat</td>
<td>Week 12</td>
<td>PB, MC</td>
<td>Telomerase activity, TRA</td>
<td>Greater TA in retreatants than controls post-retreat; TA was mediated by ↑</td>
</tr>
<tr>
<td>Daubenmier et al. (2012)</td>
<td>Overweight, obes &amp;</td>
<td>Yes</td>
<td>W</td>
<td>Mindfulness-based intervention</td>
<td>16 weeks: twice 2.5h group sessions + 1 day silent retreat</td>
<td>Baseline, post</td>
<td>PB, MC</td>
<td>Telomerase activity, TRA</td>
<td>↑ TA in both groups; changes in TA were negatively correlated with chronic stress, anxiety, dietary restraint, dietary fat intake; ↑ TA was associated with ↑ quality of life in the meditators</td>
</tr>
<tr>
<td>Lavretsky et al. (2013)</td>
<td>Dementia caregivers</td>
<td>Yes</td>
<td>Listening to meditation</td>
<td>Kiran kriya (n = 12)</td>
<td>8 weeks: CD-led meditation 12m/d</td>
<td>Baseline, post</td>
<td>PB, MC</td>
<td>Telomerase activity, TRA</td>
<td>↑ TA in meditators but not relaxation controls; ↑ TA was associated with ↑ quality of life in the meditators</td>
</tr>
<tr>
<td>Rao et al. (2015)</td>
<td>Healthy novices</td>
<td>None</td>
<td>Mindbody therapy</td>
<td>3 weeks: residential retreat including 1 h/d yoga &amp; breath exercises</td>
<td>Baseline, week 3</td>
<td>PB, MC</td>
<td>Telomerase activity, TRA</td>
<td>↑ TA; 45% of people showed TA increases of ≥ 20% in experienced meditators compared with controls</td>
<td></td>
</tr>
<tr>
<td>Kumar et al. (2015)</td>
<td>31-year-old obese man</td>
<td>None</td>
<td>Yoga-based lifestyle</td>
<td>10 days: active intervention with instructor 2 h/d, followed by 90-</td>
<td>Baseline, day 10, day 90</td>
<td>PB, MC</td>
<td>Telomerase activity, TRA</td>
<td>↑ TA</td>
<td></td>
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<tr>
<td>Eipel et al. (2016)</td>
<td>Healthy experienced</td>
<td>Naloxone &amp; vacation controls</td>
<td>Vacation controls (n=31) &amp; novice meditation</td>
<td>Primordial sound meditation retreat (n = 10)</td>
<td>4 days: residential retreat including meditation 3h/d + yoga 5h/d + lectures + interactive self-reflection</td>
<td>Baseline, day 6, week 4, month 10</td>
<td>PB, MC</td>
<td>Telomerase activity, TRA</td>
<td>↑ TA in experienced meditations (lower at baseline) but not novices or vacation controls</td>
</tr>
<tr>
<td>Ornish et al. (2008)</td>
<td>Low-risk prostate cancer</td>
<td>None</td>
<td>Comprehensive lifestyle</td>
<td>12 weeks: yoga &amp; meditation 6h/w + moderate exercise 3h/w + group support 3h/w + meetings with health staff 4h/w</td>
<td>Baseline, week 12</td>
<td>PB, MC</td>
<td>Telomerase activity, TRA</td>
<td>↑ TA associated with ↑ in LDL cholesterol and ↓ in intrusive thoughts</td>
<td></td>
</tr>
<tr>
<td>Ornish et al. (2013)</td>
<td>Low-risk prostate cancer</td>
<td>Active observer</td>
<td>Comprehensive lifestyle</td>
<td>Optional attendance of two 4h retreats/week; following the</td>
<td>Baseline, year 4-5</td>
<td>PB, MC</td>
<td>Telomerase activity, TRAPeptide kit</td>
<td>↑ TA in both groups; ↑ TL in retreatants compared with controls, No change in TA; ↑ TL in both groups compared with controls, ↑ TL in meditators compared with controls</td>
<td></td>
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<tr>
<td>Conklin et al. (2018)</td>
<td>Healthy, exp, men &amp;</td>
<td>Life as usual</td>
<td>Insight meditation retreat (n = 20)</td>
<td>4 weeks: ~ 9 h/d meditation during silent residential retreat + vegetarian diet</td>
<td>Baseline, week 3</td>
<td>PB, MC</td>
<td>Telomerase activity, TRAPeptide kit</td>
<td>↑ TA in MSBR participants (lower at baseline) compared to controls; No change in TA; ↑ TL in both groups compared with controls, ↑ TL in meditators compared with controls</td>
<td></td>
</tr>
<tr>
<td>Longacker et al. (2014)</td>
<td>Breast cancer patients</td>
<td>Treatment as usual</td>
<td>Variation of MBS retreat</td>
<td>6 weeks: meditation &amp; hatha yoga group sessions 20h ± 15–45 min formal meditation ± 15–</td>
<td>Baseline, week 6, week 12</td>
<td>PB, MC</td>
<td>Telomerase activity, TRAPeptide kit</td>
<td>↑ TA in both groups; ↑ TL in retreatants, which was moderated by levels of Agreeableness and neuroticism; changes in gene expression supporting improved telomere maintenance</td>
<td></td>
</tr>
<tr>
<td>Tolhuizen et al. (2017)</td>
<td>Healthy participants</td>
<td>None</td>
<td>Yoga and meditation lifestyle</td>
<td>12 weeks: 120m sessions including yoga, meditation, mindfulness-based group therapy</td>
<td>Baseline, week 12</td>
<td>PB, MC</td>
<td>Telomerase activity, TRAPeptide kit</td>
<td>↑ TA, no ↑ TL</td>
<td></td>
</tr>
<tr>
<td>Rimu et al. (2016)</td>
<td>Fathers of children</td>
<td>None</td>
<td>Yoga and meditation lifestyle</td>
<td>6 months: theory &amp; practice sessions 20h/d</td>
<td>Baseline, week 12, month 6</td>
<td>Sp, ELISA</td>
<td>Telomere length, ELISA</td>
<td>↑ TA in fathers of children with BR compared with controls; No change in TL</td>
<td></td>
</tr>
<tr>
<td>Wang et al. (2017)</td>
<td>Patients with depression, anxiety or stress</td>
<td>Treatment as usual (mostly CBT, n = 30)</td>
<td>Mindfulness-based group therapy</td>
<td>8 weeks: mindfulness-based group therapy + 20 min/day</td>
<td>Baseline, week 8</td>
<td>PB, MC</td>
<td>Telomerase activity, qRT-PCR</td>
<td>No change in TL</td>
<td></td>
</tr>
<tr>
<td>Thimmappaet al. (2017)</td>
<td>Residents, faculty</td>
<td>None</td>
<td>Life as usual (n = 12)</td>
<td>Heartfulness meditation retreat</td>
<td>12 weeks: meditation 20 min/week + 5 min before bed + group</td>
<td>Baseline, week 12</td>
<td>Saliva</td>
<td>Telomere length, ELISA</td>
<td>No change in TL overall; ↑ TL in meditators under 35 years old</td>
</tr>
<tr>
<td>Study</td>
<td>Intervention/Control</td>
<td>Support</td>
<td>Intervention Details</td>
<td>Telomere length</td>
<td>Methodology</td>
<td>Change in Telomere</td>
<td>Notes</td>
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<tr>
<td>Carlson et al. (2015)</td>
<td>Breast cancer survivors</td>
<td>Yes</td>
<td>12-week supportive-expressive therapy (MBSR; n=34) 8 weeks: group meetings 1.5h/w + 1 day silent retreat</td>
<td>MBSR: Baseline, week 8; SET: Baseline, week 12; Control: Baseline</td>
<td>Telomere length qPCR</td>
<td>TL was maintained in both intervention groups, but declined in controls</td>
<td></td>
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<tr>
<td>Duraimnai et al. (2015)</td>
<td>Hypertensive African Americans</td>
<td>To parent study, but not this</td>
<td>Extensive health education TM meditation + health education</td>
<td>Baseline, week 16 Telomere length &amp; hTERT mRNA expression</td>
<td>Serum Telomere-related gene expression higher in both groups. No change in hTR mRNA expression</td>
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<tr>
<td>Bhasin et al. (2013)</td>
<td>Healthy novices</td>
<td>No</td>
<td>Experienced practitioners maintaining their own practice (n=26) Relaxation Response (RR) training (n=26) 8 weeks: weekly individual training sessions from an experienced clinician + cd-led home practice 20min/day</td>
<td>Baseline, post: Samples were taken prior to, immediately after, and 15 minutes after listening to an RR-eliciting or health education recording</td>
<td>PBMC Telomere-related gene expression higher in long-term practitioners than novices (before or after 8-week training) at baseline, which ↓ in response to the RR</td>
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Note: m=min; h=hour; d=day; w=week; ↑=increases; ↓=decreases; ns=not significant